Lights in the Shadows, 3D-modelling knots with MOCASSIN

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Abstract.   Most of the enveloppes of Planetary Nebulae (and other objects like novae) are far from beeing homogeneous: clumps, knots and tails are often observed. We present here the first attempt to build a 3D-photoionization model of a knot and the corresponding tail, ionized by diffused radiation issuing from surrounding material.

1.   Introduction

High resolution images of ionized nebulae, which are readily obtainable with modern instruments (e.g. HST), have shown the material in these objects to be, in the majority of cases, very clumpy. In particular there are several small scale, high optical depth structures associated with these nebulae; the ionization structure in these regions appears to be very different from the rest of the nebular gas. For example, images of the Helix nebula (O'Dell & Handron, 1996; Burkert & O'Dell, 1998; O'Dell et al., 2003) show the presence of numerous Knots with associated radials Tails. These knots are observed in various PNs and may be a common situation. Even the recent images of novae shell show that the clumpiness is more the rule than the exeption (Bode, this conference). The emission of this high density knots could be partly responsible of the t^2 paradigm (Peimbert, 1967).

Van Blerkom & Arny (1972) described theoretically the ionization of a shadowed region illuminated by diffuse radiation coming from surrounding ionized material. More recently, Canto et al. (1998) presented an extension of this theoretical work and added results of numerical gasdynamic simulations.

We present here preliminary results of 3D photoionization models of Helix-type knots. The main goals of such models are the understanding of the structure and the formation of such knots and the determination of the chemical composition of the knots and the tails.

2.   A 3D-photoionization code is needed: MOCASSIN

The modelling of the knots using classical 1-D photoionization codes like Cloudy (Ferland, 2000) is virtually impossible, since the ionization of the tail behind the
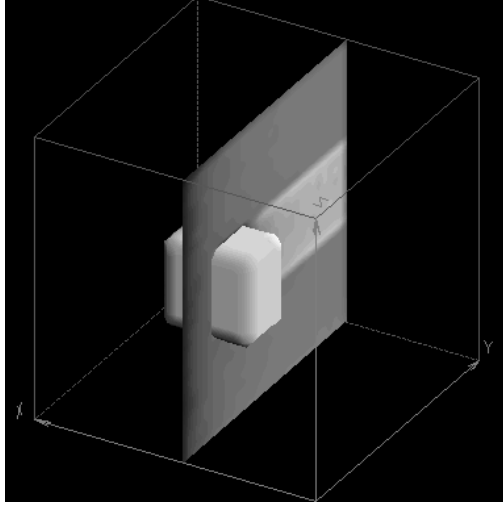
Figure 1.   Density distribution of the gas for the model of a Knot. The plane paralele ionizing flux is arriving from bottom-left.

knot due to the diffusion of ionizing photons by the surrounding material cannot be accounted for by codes based on spherical symmetry. The only way to model such geometry is to use a 2- or 3-D photoionization code.

The three-dimensional photoionization code, MOCASSIN (MOnte CArlo Simulation of Ionized Nebulae, Ercolano et al., 2003 and this conference) is used to model a cubic thick clump illuminated by plane parallel radiation (a BlackBody at 120 kK is used for this model).

3.   Modelling knots

The modeled clump has an enhanced density of 10^5 cm-3, while the surrounding gas has a density of 10^2 cm^{-3} and 1.6 10^2 cm^{-3} for the tail, in order to establish pressure equilibrium with the surrounding gas (see Fig. 1 for an illustration of the gas distribution). The assumption of pressure equilibrium between the unshielded and shadowed regions leads to an increase of the density in the shadowed region (the electron temperature being lower). The emissivity of recombination lines will then be higher in the shadow. The ionization state of the shadowed regions will be lower than in the surrounding material, which is directly illuminated by the primary radiation field, resulting in the enhanced emission from low charged ions from these regions.

A grid of 30^3 cells is used. The results of the model presented in the next section are preliminary and should only be considered as a test case with the scope to demonstrate the suitability of the MOCASSIN code to this kind of environment, rather than an attempt to reproduce all the observed characteristics of the Helix Knots.
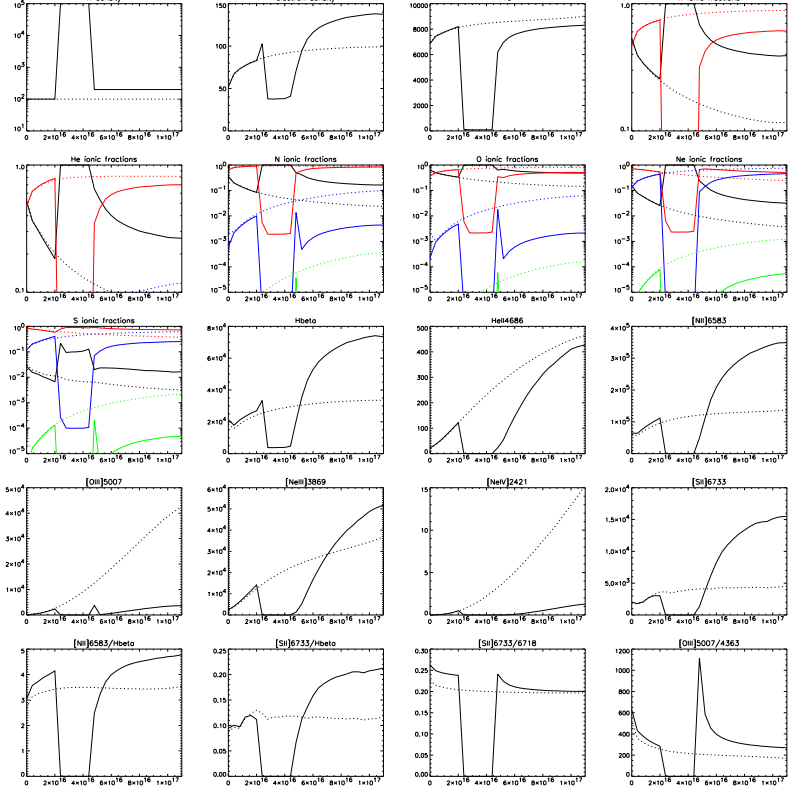
Figure 2. Results of MOCASSIN model, in the Y-axis direction, along a line crossing the dense clump (solid lines) and following a line through the surrounding directly photoionized region (dashed lines). Electron temperature and pressure, ionic fractions (black, red, blue and green for 0, 1, 2, 3 times ionized resp., color version available on astro-ph/0310***) and line emissions are presented.

4. Prelimininary results

Fig. 2 shows the results of the ionic fraction distribution and proves that the tail of the knot is effectively ionized by the diffuse radiation. Fig. 3 shows the image obtained for various emission lines, the results agree quite well with the Helix observations. Nevertheless, the contrast of emission between the tail and the surrounding material we obtain here only reproduce the observations because the geometrical depth of the surrounding material is small. If a more realistic geometry were to be used (considering the geometrical size of the tail compared to the surrounding gas), the enhanced emission of the tail would vanish; the hypothesis of pressure equilibrium seems then not to be valid.

HeII   [NII]   [OIII]
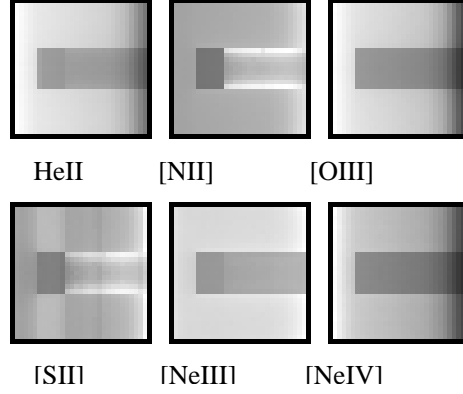
[SII]   [NeIII]   [NeIV]

Figure 3.   Synthetic images in the sky plane, for some emission lines. The main trends observed in the Helix Knots are reproduced : recombination and forbidden lines from low charged ions are emitted preferentially by the tail.

5.   Conclusion and future works

MOCASSIN is able to deal with shadows ionized by diffused radiation. The first results presented here are promising, and more realistic models will be performed to reproduce all the observational constraints obtained for the Helix knots. In particular, the hypothesis of pressure equilibrium between the tail and the surrounding gas has to be carefully investigated.

References

Burkert, A. & O'dell, C. R. 1998, ApJ, 503, 792

Canto, J., Raga, A., Steffen, W., & Shapiro, P. 1998, ApJ, 502, 695

Ercolano, B., Barlow, M. J., Storey, P. J., & Liu, X.-W. 2003, MNRAS, 340, 1136

Ferland G. J., 2000, RMxAC, 9, 153

O'dell, C. R. & Handron, K. D. 1996, AJ, 111, 1630

O'Dell, C. R., Balick, B., Hajian, A. R., Henney, W. J. & Burkert, A., 2003, RMxAA, 15, 29

Peimbert, M. 1967, ApJ, 150, 825

van Blerkom, D. & Arny, T. T. 1972, MNRAS, 156, 91